Sustainability Performance Evaluation of Renewable Energy Sources: The Case of Brazil

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Foreword

Energy in modern society is an essential ingredient for a wealth economy, like the blood circulating in our arteries.

Since the beginning of civilization, humans have learned how to use biomass combustion for cooking and heating, the wind force for navigation, and the rivers flow to move mills. With increasing world population, material progress in various parts of the world, and, especially, with the formation of large cities, new sources of energy have become necessary as coal, oil, and gas and more recently nuclear power.

In the early twentieth century, electricity production moved to the forefront as it can be converted to work with greater efficiency than coal, oil, and gas. In this century, the electrification of the world economy is intensifying significantly, since electricity consumption is increasing about 4–5% per year while the energy consumption as a whole is only growing about 2% per year. Hydroelectric, wind, and photovoltaic energy—which are renewable in contrast to electricity produced by fossil fuels—have become a priority.

In 2017, the world investment in energy production was just over US$ 1.7 trillion. US$ 718 billion was invested in the production of electricity and the remainder in the production of oil, gas, coal, and energy efficiency. Of these US$ 718 billion, US$ 277 billion was invested in power grids, US$ 193 billion in electricity generated from fossil fuels, and US$ 297 billion in renewable energy, which in 2016 were distributed as follows: wind power (39%), photovoltaics (28%), hydroelectric (26%), and nuclear (7%).

The aim of this book is to propose criteria that help public or private investors in prioritizing these investments. As an example of the application of these criteria, the authors chose and evaluated six existing plants, using three renewable energy sources (hydroelectric, wind and photovoltaic) in two regions of Brazil, South and Northeast. The studied cases were compared using several economic, environmental, and social indicators.

Three examples of scenarios representing investors interested were formulated and evaluated: primarily with focus on the financial return (scenario 1); with emphasis on social and environmental aspects (scenario 2); and investors with a

balanced view on the financial, environmental, and social aspects of the venture (scenario 3).

The final conclusion is that "although considered a clean energy source, renewable sources are not free from negative impacts. In addition, an energy source may have greater or lesser sustainability relative to other sources, depending on the region, indicators, and investors view considered in the analysis."

Only a balanced analysis can decide the best alternative. For this reason, the methodology developed in this work will certainly be very useful for public or private investors in the area of renewable energy.

São Paulo, Brazil

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About the Authors

João Fernando Gomes de Oliveira Prof. João Oliveira graduated (1982) and earned his Ph.D. (1988) in Mechanical Engineering—University of São Paulo, he was visiting scholar (1993–1994) and visiting professor (2016) at Mechanical Engineering—University of California at Berkeley. He is Professor of Mechanical Engineering at University of São Paulo with expertise in Innovation Management, Advanced Manufacturing, and Industrial Sustainability. From 2008 through 2012, he served as President and CEO of the State of São Paulo Institute for Technological Research—IPT, a state-owned research company with more than 1200 collaborators. In IPT, he implemented a large research investment program in order to support the research and development in cooperation with Brazilian companies on new energy projects such as solar, wind, hydroelectric, deepwater oil exploration, and others. He has published over 200 papers in journals, conferences, magazines, and newspapers and holds five patents registered at Brazil's National Institute of Industrial Property (INPI). He received the major science awards in Brazil, such as the Great-Cross of the National Order of Scientific Merit by the Presidency of Brazil; the Conrado Wessel Foundation Award for Science and Culture; the CAPES- Anísio Teixeira Award for his contribution to education and research; the Personality of Technology Award by the São Paulo Association of Engineers; and the SAP Americas Innovation Award. Professor Oliveira engaged in joint research with the industrial sector (TRW Automotive and Saint-Gobain Abrasives) and acted as a consultant of automotive industry worldwide including BMW, Hyundai, Chrysler, among others. He was co-founder and served as President and CEO of EMBRAPII-National Enterprise for Industrial Innovation and is member of the National Council of Science and Technology of the Brazilian Government and member of the board for several research institutes and funding organizations. He is also Fellow and Vice-President of the Brazilian Academy of Sciences and Fellow of the International Academy for Production Engineering (CIRP).

Tatiana Costa Guimarães Trindade Graduated in Environmental Engineering from the School of Engineering of São Carlos (EESC), University of São Paulo. Through the *Sciences Without Borders* Program, she had undergratuate studies at the University of Toronto, Canada, where she received a broad introduction to renewable energy and sustainability. During the exchange year, she attended the Sustainability Conference at the University of Toronto where she learned about the challenges involving energy storage and the political implications of energy supply and use. She also participated in the Technological Diffusion Course in Introduction to Solar Photovoltaic Energy, offered by the State University of Campinas (Unicamp). In addition, she was part of an online training program promoted by the Renewable Energy Observatory of Latin America and the Caribbean (UNIDO), in which she enrolled in different modules on solar, wind, and biogas energy. She developed her final project in the area of evaluation of sustainability indicators of the main renewable energy sources in Brazil.

Symbols and Abbreviations

AC	Alternated-current
AHP	Analytic Hierarchical Process
ANA	National Water Agency
ANEEL	National Electricity Agency
ANP	National Petroleum, Gas and Biofuels Agency
ASI	Aggregate Sustainability Index
BEN	National Energy Balance
BNDES	National Economic and Social Development Bank
BRL	Brazilian Currency (Real)
COGERH	Water Resources Management Company
CSD	Commission on Sustainable Development
DC	Direct-current
EEA	European Environmental Agency
EISD	Energy Indicators for Sustainable Development
EPE	Energy Research Company
Eurostat	Statistical Office of the European Communities
FU	Federative Unit
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GRI	Global Report Initiative
GW	Gigawatt
GWEC	Global Wind Energy Council
GWh	Gigawatt-hour
HPP	Hydroelectric Power Plant
IAEA	International Atomic Energy Agency
IBGE	Brazilian Institute of Geography and Statistics
IC	Total Cost to Install the Power Generation
IEA	International Energy Agency
INPE	National Institute of Spatial Research
IP	Installed Power

IPCC	Intergovernmental Panel on Climate Change
IPEA	Institute of Applied Economic Research
ISED	Indicators for Sustainable Energy Development
JPOI	Johannesburg Plan of Implementation
kV	kilovolt
kVA	kilovolt-ampere
kW	kilowatt
kWh	kilowatt-hour
LCA	Life Cycle Analysis
LPG	Liquefied Petroleum Gas
MDG	Millennium Development Goals
MJ	Mega joules
MME	Mines and Energy Ministry
Mtoe	Million Tonnes of Oil Equivalent
MW	Megawatts
MWh	Megawatt-hour
PROINFA	Alternative Energy Sources Incentive Program
PSPP	Photovoltaic Solar Power Plant
PV	Photovoltaic Cell
RFS	Reduced Flow Section
SDG	Sustainable Development Goals
SHP	Small Hydroelectric Plant
SIN	National Interconnected Electric System
TWh	Terawatt-hours
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
USD	United States currency (Dollar)
WEC	World Energy Council
WPP	Wind Power Plan
WSSD	World Summit on Sustainable Development
WWEA	World Wind Energy Association
WWF	Worldwide Fund for Nature

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Introduction

Energy is an indispensable element for the survival and development of modern society. From the use of heat in industries to the heating of a house, from feeding a freighter to fueling a motorcycle, from automating an entire production process to lighting an office lamp, energy use is an essential part of our everyday life across different scales and forms of utilizing it. With the development of new technologies, coupled with the exorbitant growth of the world population and the emergence of new needs, one of the great challenges we currently face is the uncertainty of energy availability in the future given its current demand, primarily due to the extensive use of nonrenewable sources and the large-scale exploitation of the planet's natural resources.

Since the advent of the Industrial Revolution, energy has become intrinsically associated with the economic competitiveness of nations and their quality of life. In this context, economies with greater access to inexpensive energy resources, with low environmental impact, guarantee significant market advantages. Therefore, the search for new renewable energy sources reflects not only the current need for diversifying the world energy matrix, but also the inevitability of developing alternatives that can reduce the impacts caused by the generation, distribution, and consumption of energy. It is from this perspective that discussions arise regarding technical, economic, environmental, and social feasibility for implementing renewable energy systems.

This discussion has reached such great importance in the international context that the access to "Clean and Affordable Energy" has become one of the 17 Sustainable Development Goals (SDG) listed in the 2030 Agenda, created by the Member States of the United Nations. The 2030 Agenda is a global result of the joint work of governments and citizens aimed at creating a new model for ending poverty, promoting prosperity and social welfare, protecting the environment and combating climate change (Organização das Nações Unidas 2017). The established SDGs, successors of the Millennium Development Goals (MDGs), cover very broad but interlinked areas, ranging from equitable access to quality education and health services to energy and environmental sustainability.

More specifically, SDG No. 7 states that countries adopting the action plan set out in the Agenda should "ensure reliable, sustainable, modern and affordable access to energy for all" (UN 2017). To achieve this objective by 2030, these countries should substantially increase the share of renewable energy in the global energy matrix and strengthen international cooperation to facilitate access to research and clean energy technologies, including renewable energy, energy efficiency, and advanced fossil fuels. In addition, they should also promote investment in energy infrastructure and cleaner energy technologies (UN 2017).

Brazil was one of the 193 UN member states to adopt the 2030 Agenda, with increasing attention being paid to the discussion and search for a cleaner energy matrix. In the national context, in the coming decades, this energy issue is presented to the country as both a challenge and an opportunity (Tolmasquim 2016). A challenge, as economic and social development will require an expressive amount of energy and, consequently, a high degree of security and energy sustainability. An opportunity, given Brazil's very interesting conditions of renewable energy resources and technology to harness the energy of its various natural resources (Tolmasquim 2016).

In view of the previously elucidated problem, this book presents a methodology for the sustainability performance assessment and its application in different renewable energy production projects, in order to identify the potentials of different regions and to evaluate the sustainability of each system. Thus, a case study of electricity power plants is presented regarding different renewable energy sources in different regions of Brazil. The analysis helps in determining which projects perform better, according to different considered scenarios. The analysis is carried out based on performance indicators obtained from a survey on the characteristics of the studied projects and from the existing literature.

Besides this introductory Preface, this book has six chapters, organized as follows:

- Chapters 1–3 contain definitions, information, and data on the world energy matrix, specific, selected renewable energy sources, and sustainability indicators;
- Chapter 4 describes the main sustainability indicators used in the sustainability analysis of renewable energy generation systems and how to select them for the application in a sustainable energy endeavor;
- Chapter 5 presents a methodology for the sustainability performance analysis of different renewable energy technologies;
- Chapter 6 shows in detail the application and discussion of the sustainability performance analysis developed for a Brazilian case study, following the proposed methodology.

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